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DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
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ICELAND SPAR AND OPTICAL FLUORITE

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ICELAND SPAR AND OPTICAL FLUORITE[1]

By H. Herbert Hughes[2]

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ICELAND SPAR

Introduction

Iceland spar is a variety of calcite (calcium carbonate) characterized by its purity, transparency, and perfection of crystalline structure. It takes its name from the country in which it was discovered. The actual demand for it is small, but the supplies of high-grade optical spar are so meager that the search for it has become international in its scope. Iceland spar is a scientific necessity, for without it research precision and technology would be hampered considerably.

The earliest students of mineralogy were familiar with calcite, but the transparent variety was not discovered until early in the seventeenth century, when crystals of it were found in the bed of a stream in Iceland. It received little attention until 1669, when Erasmus Bartholinus first recognized its powers of double refraction. The results of his investigation were published in a book, "Experimenta Crystalli Islandici," which appeared in 1670. The law governing the action of the rerracted rays was discovered by Christian Huygens eight years later.

The polarization of light rays in passing through Iceland spar was discovered in 1809 by Etienne Louis Malus, a French physicist, who published a paper describing the phenomenon. His work was closely followed by that of William Nicol, who in 1828 designed the Nicol prism which is still used as the source of polarized light in most optical instruments.

Acknowledgment

Much of the information contained in this paper was taken from a report on Iceland spar by Oliver Bowles[3] which is no longer available.

Uses

By far the most important use of Iceland spar is for the manufacture of Nicol prisms, which are an essential part of every polarizing microscope and which are used also in saccharimeters, dichroscopes, photometers, colorimeters, and polariscopes.

An ordinary light ray is extremely complex; its vibrations take place in all possible planes intersecting the ray as an axis. When such a light ray passes through a rhombohedron of calcite, however, it is resolved into two rays of plane polarized light, each vibrating in a single plane perpendicular to the other. Furthermore, the two rays have different indexes of refraction, which results in their following different paths through the crystal. This phenomenon can be observed by placing a cleavage fragment of calcite over a dot on a piece of paper. Two dots will appear and, upon rotating the crystal, one will revolve around the other. These two rays are commonly known respectively as the ordinary and the extraordinary.

The Nicol prism is an ingenious device which utilizes these properties in providing a source of plane polarized light. It is constructed of clear, flawless calcite in such a manner that the ordinary ray is reflected and totally absorbed within the Nicol while the

3 - Bowles, Oliver, Iceland spar: Rept. of Investigations 2238, Bureau of Mines, 1920, 6 pp.

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extraordinary ray emerges as polarized light vibrating in only one plane. A cleavage rhombohedron of Iceland spar about three times as long as it is broad is cut diagonally along the plane connecting the obtuse dihedral angles of two opposite elongated faces, and the end surfaces are ground down until they are perpendicular to this newly formed plane. The two halves are then cemented together with Canada balsam, a transparent cement having an index of refraction lying between the values of the indexes of the two rays common to calcite. The cemented Nicol is polished and then set in cork, blackened along the contact with the calcite in order to absorb light which is reflected to the sides.

Immediately upon entering the Nicol, any ray of white light is broken into two rays, the ordinary and the extraordinary. The ordinary ray has a higher index of refraction and, therefore, it is refracted to a greater extent than the extraordinary. As a result, it meets the Canada balsam at an angle so great that it is reflected from it and is absorbed by the blackened walls of the prism. The extraordinary ray, because of its lower index of refraction in this direction through the crystal, meets the Canada balsam at a lesser angle and passes through it without being appreciably affected. This ray emerges from the opposite end of the Nicol as plane polarized light with its vibration plane parallel to the short diagonal of the rhombic section of the prism, and polarized in the plane parallel to the film of Canada balsam. This vibration plane is rigidly fixed by the crystalline structure of the calcite. Modifications of this style of Nicol have been devised, but they all embody the principle of totally reflecting either the ordinary or the extraordinary ray.

By means of the petrographic microscope, which uses two Nicol prisms, the behaviour of polarized light in traversing thin sections of minerals can be studied. The optical properties thus revealed provide an accurate means of identification for most minerals. Iceland spar, therefore, is of inestimable value in the scientific investigation of rocks and minerals. Nicol prisms or modifications of them are used in other scientific equipment which aids manufacturers in keeping a close check on the quality and uniformity of their products. Among these instruments are saccharimeters, which are used to measure the sugar content of a solution; colorimeters, which indicate depth of color as compared with a standard; photometers, which measure intensity of light; dichroscopes, which reveal dichroism in crystals; polariscopes, and polarimeters, which are used in the study of polarized light; spectrometers, which are used in determining index of refraction; and spectroscopes, which are used in forming and examining spectra. Iceland spar is also used in the determination of crystal structure by X-ray analysis.

Only a small percentage of the spar recovered from most deposits is of optical grade, and unfortunately there is practically no market for material which is too cloudy or otherwise too imperfect for optical use. Many fine crystals of Iceland spar have been acquired by various museums, but this market is in direct competition with optical manufacturers. Probably the finest specimen is the one in the British Museum. It is a section of a large crystal about 24 inches across and at least 16 inches thick, practically free from fractures or inclusions. The crystal was taken from the Iceland deposit during the early years of its operation.

Numerous smaller specimens are sold to museums, colleges, schools, or private collectors either as additions to mineral collections or for demonstration of optical properties. This market provides an outlet for material which is slightly inferior to high-grade optical spar. The quantity actually consumed for these purposes, however, is small compared with the waste material available at most deposits, and prices are low; hence, sale of collection specimens has little effect on the lowering of unit production costs.

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A small quantity of chemically pure Iceland spar is consumed by manufacturing chemists in the preparation of standardizing solutions for use in volumetric analysis. The demand for standardizing spar is small, although it is possible that a thorough canvass of the chemical industries might establish a market which would absorb much of the waste material.

Pure calcium carbonate is used also in the manufacture of special kinds of glass, as whiting substitute, in the preparation of chemical lime, as a filler in various products, and for numerous other purposes, but for these uses optical properties are nonessential, and the markets are being supplied with high-grade limestone or marble which can be produced in large quantities for only a few dollars a ton.

The auxiliary uses of Iceland spar are comparatively insignificant, and anyone contemplating the exploitation of a spar deposit should assure himself that quantities of optical-grade material sufficient to warrant the cost of development are available.

Physical Properties

Two properties of Iceland spar must be carefully considered by those mining and handling the material. One is its perfect rhombohedral cleavage. Iceland spar splits in three directions at oblique angles. Every cleavage fragment, regardless of its size, possesses this rhombohedral form, resembling a soft brick which has been pushed over from one corner, with the result that the whole brick is lopsided. Althougn this cleavage necessitates using extreme care in mining the material, it is decidedly helpful in trimming rough crystals and in breaking up large masses. This work, however, should be done by an expert thoroughly familiar with the properties of calcite, for one misdirected blow may cause incipient fractures throughout the whole crystal and entirely ruin it for optical use.

The other property is hardness. Iceland spar is merely pure crystallized limestone, therefore it is quite soft and can easily be cut or scratched with a knife. In packing for shipment each piece should be wrapped separately in order to prevent abrasion of the crystals against each other or against the sides of the container.

Specifications for Iceland spar suitable for optical uses are rigid. The crystals or cleavage fragments must be at least 1 inch long and half an inch thick each way. Pieces smaller than this are rarely acceptable as optical spar. Each piece must be colorless and absolutely transparent, completely free from cloudy inclusions, cavities, or foreign particles. The material must not show any internal iridescence or rainbow colors due to incipient cracks along cleavage planes. Even twinning lamellae which are invisible to the naked eye may ruin some specimens for optical use. The imperfections and inclusions are not always scattered throughout the entire crystal, and each specimen should be examined from every direction in order to detect the presence of all defects. It is sometimes possible to trim away imperfect portions of large crystals and recover cleavage fragments of satisfactory spar. Whenever feasible, all trimming should be done by an experienced person.

A twin crystal can be identified by placing it over a dot on a piece of paper. If the crystal is normal, two dots will appear which will vary little regardless of movement of the crystal along the paper. In moving a twin crystal slowly back and forth, however, additional indistinct dots may also appear in various positions. Twinning ordinarily ruins a crystal for optical use but it is possible in some instances to cut the crystal in such a manner that the undesirable twinning phenomena are eliminated.

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Geology

Iceland spar is formed by deposition of calcium carbonate from water solution, but the conditions necessary for the formation of transparent spar rather than ordinary calcite are not definitely known. No blanket statement covering geologic occurrence of the material can be made. In general, however, the principal deposits are associated with basic igneous rocks, occurring as masses or crystal aggregates in cavities of the country rock. These pockets are usually filled with residual clay. The belief that the calcite has been deposited from magmatic (deap-seated) rather than meteoric solutions has many supporters, but there is little evidence to support this theory. Other minor deposits of Iceland spar, usually of inferior quality, occur as vein material in limestones and related rocks.

Mining Methods

Ordinary open-pit methods of mining have been used in most Iceland spar operations. The country rock is broken up by explosives, after which the clay pockets are worked out by hand to recover the spar crystals. These, in turn, may be broken by small hand hammers into pieces more easily handled. Iceland spar is easily shattered, and this rough treatment undoubtedly is responsible for a large proportion of the incipient fractures in the finished product. The use of explosives in mining this material can not be too strongly condemned, for even though the masses of spar may be partially cushioned by the clay surrounding them, blasting ruins many of the crystals.

The best method of mining could be determined only by a careful study of the deposit itself. Most marble deposits are worked by channeling and wedging, without the use of explosives, in order to avoid fracturing the material. Careful handling certainly is more important with Iceland spar than with building and ornamental stone. Marble-quarrying methods might be advantageously applied to spar deposits. A channeling machine could be used to make wall cuts along the sides of the veins, after which large masses of the rock could be split off by drilling and wedging. Subsequent reduction in size of fragments might be accomplished best by means of wooden wedges and mallets. Most Iceland spar operations are too small to justify the expense of a channeling machine, but a substitute method of wedging in drill holes might be devised. Regardless of the mining method selected, the operator always should bear in mind that the fragile nature of the material demands extreme care throughout the entire procedure.

An interesting departure from conventional quarrying methods is the use of unslaked lime rather than explosives in breaking the rock surrounding the crystals. This procedure eliminates the danger of fracturing the spar by blasting. The method itself is simple. Three or four inches of unslaked lime is tamped in the bottom of a hole drilled a short distance from the crystals. A slender iron rod or wire is inserted into the hole, and lime is packed around it to within 2 inches of the top by means of a curved tamping bar. The rod is then removed, and a cotton string saturated with water is dropped into the hole so that the end is suspended about half an inch off the bottom. The opening of the hole is then sealed with clay or some other similar material. The water dripping from the string causes expansion of the lime which bursts the rock with a minimum of damage to the spar. This method was suggested to the bureau in 1929 by Oscar H. V. Berghland of California.

A system of underground mining was at one time being considered for the Iceland deposit. The principal advantages of the proposed plan were that it would permit continuous

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operation throughout the year, workmen would be sheltered from inclement weather, the danger from rock falls would be reduced, and the spar crystals would be protected from frost and other weathering agencies. These features were particularly applicable to the Iceland mine, for the rigorous Icelandic winters greatly hamper any outdoor activities. However, the possibility of underground mining should not be overlooked during the development of any deposit, providing that the operator has done enough exploration work to assure himself that the reserves of material justify the investment.

Consumption and Prices

Before the World War European companies, particularly German firms, supplied practically all of the Nicol prisms and other Iceland spar parts used by the American manufacturers of scientific apparatus. During the war, however, rapid depletion of stocks of finished prisms forced the American companies into the manufacture of these essential parts. The present domestic production of Nicol prisms is being supplemented by imports, and there is a ready market, both in the United States and abroad, for high-grade optical spar.

No production or consumption figures for Iceland spar are available, but the quantity actually sold in the United States is small, probably not more than 200 or 300 pounds a year. The total poundage in recent years evidently has represented the entire quantity of material offered for sale, because the optical manufacturers report that they have been attempting ineffectually to build up a reserve supply. The volume of foreign consumption no doubt is considerably greater.

No definite price for Iceland spar can be quoted. In many transactions a fair price is arrived at by negotiation between the buyer and seller. The principal factors influencing price are the quality of the spar, the size of the fragments or crystals, and the quantity to be sold. The status of the reserve supplies of the purchasing company exerts a pronounced influence on prices; a manufacturer with a large reserve of optical spar will not pay as high a price as another manufacturer whose supplies are nearly exhausted. The price of optical-grade spar during the past five years has fluctuated from $7 to $35 a pound. Both of these limits are extreme - $10 to $25 probably would be more nearly normal. Seasonal trends and general business depressions have little effect on Iceland spar. Prices during 1930 and now are reported to be as high or possibly higher than at any time since the war.

The average price for museum or collection specimens is about $1 to $3 a pound, although the value of extra-fine crystals is equivalent to that of optical-grade material. Standardizing spar usually sells for $1 to $2 a pound.

Markets

Several companies in the United States manufacture scientific equipment, but only the following two firms are consumers of Iceland spar. Both of these companies have recently reported to the Bureau of Mines that they are interested in locating additional sources of optical-grade material.

Bausch and Lomb Optical Co., 637 St. Paul Street, Rochester, N.Y.
Spencer Lens Co., 19 Doat Street, Buffalo, N. Y.

The following foreign manufacturers of optical instruments are potential buyers of high-grade spar.

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Carl Zeiss, Jena, Germany (Sales Office: 485 Fifth Avenue, New York, N. Y.).
E. Leitz, Wetzlar, Germany (Sales Office: 60 East Tenth Street, New York, N. Y.).
C. P. Goertz, Stuttgart, Germany.
I.C.A.A.G., Stuttgart, Germany.
Contessa Nettel A. G., Stuttgart, Germany.
Ernemann A. G., Dresden, Germany.
Hollein & Reinhardt, Neuhausrennweg, Germany.
Kroger & Ihlenfeld, Blankanese, Germany.
Adam Hilger, Ltd., 75a. Camden Road, London, England.
Short & Mason, Ltd., London, England.
Societe Genevoise d'Instruments de Physique, Geneva, Switzerland (Sales Office: Investment Building, Washington, D. C.).

Mineral dealers constitute an outlet for small quantities of Iceland spar, both for optical-grade material and for museum or collection specimens. Some of the most important companies engaged in the mineral supply business are given in the following list.

Wards Natural Science Establishment, Inc., P. O. Box 24, Beechwood Station, Rochester, N. Y.
Foote Mineral Company, Inc., 1610 Summer Street, Philadelphia, Pa.
R. M. Wilkie, Palo Alto, Calif.
John B. Litsey, P. O. Box 592, Dallas, Tex.
Lundholm and Co., 3303 Foster Avenue, Chicago, Ill.
S. and M. Mineral Supply House, R.F.D. 3, Box 284, Riverside, Calif.
J. A. Grenzig, 299 Adams Street, Brooklyn, N. Y.
Peter Zodac, Peekskill, N. Y.
R. W. Tuthill, 110 Earl Road, Michigan City, Ind.
Eimer & Amend, 201 East 13th Street, New York, N. Y.

No attempt has been made to compile a complete list of possible buyers for standardizing spar because, although such firms are numerous, the quantity sold is small and the price is low. Any producer who is interested in building up such a market for waste spar will be able to find the principal chemical companies and chemists' supply houses listed in Thomas' Register of American Manufacturers or in the Chemical Engineering Catalog, which are available in most libraries, Chambers of Commerce, and offices of other trade associations. The following companies, however, in reply to a questionnaire sent out by the Bureau of Mines, reported that they were buyers of Iceland spar in limited quantities, apparently for chemical uses.

A. D. Mackay, 26 Cortlandt Street, New York, N. Y.
The Exolon Co., Commercial Ave., & Erie R.R., Blasdell, N. Y.
The Harshaw Chemical Co. of N. Y., 150 Nassau Street, New York, N. Y.
The Globe Chemical Co., Murray Road & Big Four R.R., St. Bernard, Cincinnati, Ohio.
Charlotte Chemical Laboratories, Charlotte, N. C.
Los Angeles Chemical Co., 1960 Santa Fe Ave., Los Angeles, Calif.
Braun Corporation, 363 New High Street, Los Angeles, Calif.
Algernon Lewin Curtis, P. O. Box 61, Westmoor Laboratory, Chatteris, England.

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Occurrences

Deposits of Iceland spar have been reported in many of the Western States and in several foreign countries, but actual commercial production at present seems to be confined to South Africa and possibly Spain. The known reserves of optical spar available in this country are small and are associated with so much imperfect worthless material that operating costs are prohibitive. No complete list of Iceland spar producers can be compiled, but the following descriptions of the principal deposits include a summary of the present status of each occurrence, as well as names and addresses of persons who can furnish either optical spar or further information.

Iceland.- The spar mine in Iceland is near the farm Helgustadir, about one hour's ride from Eskifjordur, a trading station on the east coast of the island. The deposit lies approximately 345 feet above sea level.

The deposit was discovered during the early part of the seventeenth century, but little attention was given it prior to 1650. After the work of Bartholinus and Huygens it attracted considerable attention, but actual development of the property was not begun until 1850. At that time part of the deposit was privately owned and part owned by the Government, but in 1879 the Government obtained entire control, and all operations since then have been under Governmental supervision, either directly or by lease to native or foreign companies.

The country rock consists of a series of basalt-lavas in alternating beds of unaltered and decomposed rock. Numerous small crystals of calcite are found in the many joints and crevices of the basalt. Disintegration of the rock has formed larger openings in some parts of the deposit, and these cavities are partially filled with residual red clay. Crystals of the best quality are found embedded in this clay. The first large cavity which was discovered was reported to have been practically filled with pure crystallized masses and enormous crystals, the largest ones being a yard across. The crystals are rhombohedral or scalenohedral in habit; the faces are usually well developed but are commonly coated with stilbite. Other zeolites occur around the edges of the clay pockets. The spar crystals which are unprotected by the clay are usually imperfect.

Eiriksson's[4] theory for the origin of the calcite is interesting. He contends that the alteration of the basalt is not due to weathering but to the action of heated ascending waters which probably also brought up much of the calcium carbonate. This theory is partially substantiated by the fact that the clay pockets seem to increase in size with depth, and further, that the crystals in the deeper cavities are larger and of better quality than those lying near the surface.

No description of the Iceland quarry has been published since Eiriksson's report, but in 1919 the pit was 100 feet long and 72 feet wide at the top. The average depth was 52 feet and the bottom dimensions were about 55 by 50 feet. No definite order or system of development was followed, the clay pockets being worked out by hand with picks and shovels wherever they were found. The largest clay pockets containing the most perfect crystals were found in the southwestern corner of the pit. Undercutting in this corner left a dangerous overhang of rock which made further progress in that direction extremely hazardous. Eiriksson strongly recommended that the open-pit method of mining be abandoned in favor of underground development.

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4 - Eiriksson, Helgi H., The Spar Mine at Helgustadir, Iceland: Trans. Inst. Min. Eng., London, vol. 59, March, 1920, p. 56.

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The spar crystals from the Iceland mine are variable in size, and as in every deposit, many of them are too imperfect for optical use. In addition to cracks and distortions the principal imperfections are air bubbles, included water, and streaks of clay or other foreign mineral matter. Operations were discontinued for several years during the World War and the quarry was flooded in order to protect the crystals from weathering. Since it has been reopened, especially during the past few years, the quality of the material has been far below the standard of the pre-war product. As a result, the deposit has been worked only intermittently, and the consumers have been forced to locate supplies of optical grade spar elsewhere. Careful subsurface exploration might reveal additional clay pockets containing high-grade material, but doubt has been expressed as to whether the cost of such an investigation would be justified.

Spain.- About 1913, a small quantity of Iceland spar was produced in Spain and shipped to Germany by Felipe Azcarate of Bilbao. A shipment of material from this source was received in the United States, but it was found to be unsuited for optical uses. However, it was rated by the shipper as third-class spar, and therefore it can not be taken as representative of the material which was supplied to the German manufacturers. It was reported that preparations for expansion of operations at this deposit were interrupted by the war. No further information has been received regarding the location of the mine, the extent of the deposit, or present developments. However, shipments of optical-grade spar from Spain have been received in the United States during the past year. This would indicate renewal of mining activity, but it does not necessarily reveal the scope of the operation, because most of the production might logically be consumed in European markets.

South America.- In 1920 samples of Iceland spar from Buenos Aires, Argentina, were sent to the United States to be tested for use in optical equipment. It was reported that the quality of the material was good enough to warrant an investigation of the source of supply. Nothing further seems to be known regarding the deposit, and it may have been of no importance.

One of the American manufacturers reported in 1921 that Iceland spar could be purchased in Brazil, but no further details regarding its occurrence in that country have been forthcoming.

Canada.- Glenn, Kirkpatrick, and Armstrong of Beaton, B. C., reported an occurrence of Iceland spar to Norton F. Brand, American Consul, Fernie, B. C., in 1921. The deposit was located near the headwaters of Lake Creek in the Trout Lake mining district about 20 miles from Ferguson. In 1930 Brand stated that all three of the discoverers had since died and that the claims are probably abandoned. Estimates of the quality of the spar are conflicting, but the locality may merit further investigation. B. T. O'Grady, resident mining engineer, Nelson, B. C., is familiar with the geology of the area and with the history of previous exploration.

A description of Iceland spar specimens apparently close to optical-grade material was received in 1931 from W. A. Bower, 839 Hastings Street, Vancouver, Canada. Nothing further has been learned regarding the source or the actual quality of the spar.

Henry M. Eakin, 914 Excelsior Life Building, Toronto, Ontario, submitted samples of calcite approaching optical spar to the Bureau of Mines, but nothing further is known regarding the possibilities of this source of supply.

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Australia.- No specimens of Iceland spar or definite information regarding its occurrence have been received to substantiate the rumors of deposits having been found in Australia. However, M. S. Buchanan, 253 Allison Road, Coogee, New South Wales, in a letter dated January 2, 1931, requested information regarding buyers of Iceland spar in the United States, and an investigation of his inquiry might reveal an additional source of optical-grade material.

Spitsbergen.- Casual mention of the occurrence of Iceland spar in Spitsbergen has been made in articles in trade journals, but nothing could be learned regarding the extent of the alleged deposits or the quality of the spar.

Greycliff, Mont.- Deposits of Iceland spar near Greycliff and Big Timber in Sweet Grass County, Mont., were first reported to the Bureau of Mines in 1916. Samples of the spar received at that time indicated that the material had commercial possibilities and S. C. Lind, a member of the staff of the Bureau of Mines Experiment Station at Golden, Colo., made an investigation of the deposit. Most of the information given in this description has been taken from Dr. Lind's report.

The spar was first discovered by W. E. Burch about 1907. The deposit which he located is about 12 miles southwest of Greycliff, which is on the main line of the Northern Pacific Railroad 71 miles west of Billings. A shaft was sunk to a depth of about 75 feet and 30 or 40 tons of calcite was taken out. About 600 pounds of the best material was shipped to New York and ultimately to Germany. Another deposit about 1 mile closer to Greycliff was opened later by R. H. Cartwright, and samples of the best crystals were sent to London and to Philadelphia. No report of the optical properties of the spar is available from either source. A third deposit was discovered about 10 miles west of Greycliff and 4 miles from Big Timber.

The spar at the Cartwright operation, which is the largest deposit, occurs in two parallel vertical veins striking northwest and southeast. One is about 7 feet wide and the other 5 feet. They apparently extend for several miles, maintaining their width and direction with remarkable constancy. The depth of the veins is not known, but there is evidently a large reserve supply of spar. There is little overburden, and the vein is nearly all calcite.

Chemically the spar is practically pure calcium carbonate, but most of the material has not been suitable for optical uses. Three kinds of imperfections are prevalent. Some of the crystals are cloudy, but since this turbidity affects only a small percentage of the material it is of no serious consequence. The principal defect is the abundance of incipient cleavage cracks in the interior of the crystals which render much of the spar unfit for optical uses. The cracks may be due partly to rough handling, but many of them appear to be inherent in the calcite. Many of the crystals are complexly twinned.

Little can be learned about the subsequent status of the operation. R. H. Cartwright, Greycliff, Mont., and Professor J. P. Rowe, Missoula, Mont., worked the deposit intermittently for several years and sold a small quantity of optical spar, although none of it has been used by domestic manufacturers during the past five years. From the nature of the material, it seems logical to assume that the preponderance of imperfect crystals made production costs too high for economical operation. From the standpoint of reserves, however, the location is interesting, for in an emergency when foreign supplies are not available, optical spar could no doubt be produced.

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Cedarville, Calif.- The occurrence of Iceland spar in the Warner Range near Cedarville, Modoc County, Calif., was first brought to the attention of the Bureau of Mines by James D. Patterson in 1920. This deposit was worked intermittently for a few years, but production was discontinued before 1925.

No study of this occurrence was ever made by any bureau representative, but reports from the operators indicate that the calcite occurred in veins or cavities varying in thickness from a few inches to several feet, the country rock being dark and heavy, probably a basalt. Nearly all the pockets or cavities contained crystals of Iceland spar, the larger crystals occurring in soft decomposed rock of the consistency of clay. Unfortunately, however, the deposit was shallow and the quantity of spar recovered from the operation was much less than the owners anticipated. Specimens varied in size from a marble to large crystal aggregates weighing 60 to 80 pounds. Nearly all of the clear crystals were covered with a reddish coating having a burned appearance, and they emitted a characteristic ringing sound when struck with a hammer. Many of the crystals were twinned. All mining was by open cut.

No statistics are available regarding the total quantity of optical-grade spar produced. During the winter of 1920-1921, which was apparently the most active year, about 1,000 ounces of spar was sold. The price was $8 a pound for pieces weighing 1 ounce, with a premium of 50 cents additional for each one-fourth ounce increase in weight of the crystals. The largest crystal shipped during that year weighed 12 ounces. The percentage of flawless crystals was low, but they were of excellent quality, giving satisfactory service in optical instruments. At the time of its discovery this deposit was expected to constitute an important source of supply of optical spar, but the limited extent of the occurrence prevented extensive development.

Pyramid Lake, Nev.- James D. Patterson was also responsible for the discovery of an Iceland spar deposit near Pyramid Lake, Nev. The occurrence was reported to be geologically similar to the Cedarville deposit, but it was found to be of limited extent and of no commercial importance.

Miscellaneous.- Many of the numerous samples of Iceland spar submitted to the Bureau of Mines for examination within the past year approach optical-grade material, but none of the specimens has been perfect enough to be satisfactory for optical uses. Most of the alleged deposits are in the Western States. The two following correspondents have notified the bureau that they can supply Iceland spar, but the quality of the material is not known.

A. H. Scott, Box 777, Lovelock, Nev.
Philip S. Hoyt, Las Tablas, N. Mex.

Some of the calcite commonly associated with the lead and zinc ores of the Joplin district is almost sufficiently transparent and perfect to be classed as Iceland spar. No optical use of it, however, has been reported to the bureau.

South Africa.- The present demand for Iceland spar is being supplied principally from South Africa. Most of the information regarding the deposits has been procured through the cooperation of W. Kupferburger, Mineral Technologist of the Board of Trade and Industries, Union of South Africa.

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The most important locality is the Kenhardt district, northwest Cape Province, where numerous deposits are scattered over a large area. The spar occurs as irregular masses of various sizes imbedded in soft sandy clay which fills cavities in weathered diabase. The spar is recovered solely by hand methods.

Iceland spar probably was discovered first by early South African explorers, but its value was not recognized until about 1920 when small shipments were sent to Germany. E. G. Bryant claims the distinction of having pioneered this early development. Most of the material is sold to German manufacturers, but small quantities of South African spar have been imported into the United States during the past five years. Production is not continuous, but the following persons have been working the material intermittently since 1922 or earlier.

E. G. Bryant, Box 11, Prieska, C. P., Union of South Africa.
L. F. Dawson, Hanover, C. P., Union of South Africa.
D. Scharff, Box 12, Kenhardt, C. P., Union of South Africa.

Samples of spar submitted to Kupferburger by F. J. Jooste, Box 9, Mariental, Southwest Africa, appear to be of optical grade, but neither the exact location nor the extent of the deposit is known. Specimens from other localities in the Union have not been satisfactory, although the fractures in some of them may have been caused by improper handling.

Present available evidence indicates that the Union of South Africa must be relied upon to furnish Iceland spar to the markets of the world. However, the situation is parallel to that of 20 years ago when Iceland dominated the industry. Only time can reveal future trends.

OPTICAL FLUORITE

Introduction

Fluorite, calcium fluoride, is a mineral used extensively as a flux in the metallurgical industries and to a lesser extent in the manufacture of hydrofluoric acid, glazes, enamels, and opalescent glass. It is commonly known to the trade as fluorspar.

Fluorite is slightly harder than Iceland spar, but it can be scratched easily with a knife. A diagnostic difference between the two minerals is cleavage. Fluorite has perfect cleavage in four directions. Each fragment is a double four-sided pyramid commonly known as an octahedron. Like Iceland spar, it is used in the manufacture of optical instruments; transparent, flawless crystals are sold at premium prices for use in lenses and lens systems to correct chromatic and spherical aberration.

Little seems to be known regarding the early use of fluorite in optical apparatus. At present, however, it is an essential part of many lenses and it no doubt would be used more extensively if sufficient supplies of optical-grade material were available.

Properties and Uses

The following information regarding the properties and uses of optical fluorite is

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quoted from a paper by Joseph E. Pogue[5] which describes the optical fluorite resources of southern Illinois.

> Each transparent mineral not only bends or refracts rays of light in a definite and characteristic manner, but bends the colored components of the individual rays at slightly different angles - a property called dispersion. In addition to this, most minerals break light into two rays, each of which is both refracted and dispersed; only minerals that crystallize in very symmetrical forms, such as cubes or octahedrons, do not show this double refraction. Fluorite bends light very slightly (has a low index of refraction); disperses light faintly (that is, its refraction of red rays differs only a little from its refraction of yellow rays and so on); and normally displays no double refraction. These three properties place fluorite in a unique position among minerals and fit it for a highly specialized optical use which no other mineral or artificial substance can meet equally well. Only three or four other minerals have lower refraction than fluorite; but these are either colored or are not sufficiently transparent, and moreover show marked double refraction as a result of their crystallization. Hence fluorite stands alone.
>
> Glass, of a special kind, is the dominant material used in all optical apparatus. By varying the chemical composition of the glass and the shape of the lenses and prisms made from it, the various optical effects desired are obtained. Owing to the reflection of light from surfaces and a breaking up or dispersion of light in passing through a substance, errors are introduced, and to neutralize or minimize these errors calls for the best efforts of technical art and scientific knowledge. It is here that optical fluorite finds its chief use.[6] Due to its low refractive power and very weak color dispersion, this mineral is especially suitable for correcting the spherical and chromatic errors of lens-systems. The so-called apochromatic objective used with microscopes consists of a lens of fluorite placed between lenses of glass and represents the finest type of objective that optical art produces. There are two other classes of objectives, less fine and less costly, the achromat and the semiapochromat; fluorspar is used only in the second of these, which is a sort of compromise between the cruder achromat and the more nearly perfect apochromat. The less expensive semiapochromat could replace the apochromat in many instances, were optical fluorite more available; but at present the manufacturer is forced to conserve his meagre supplies of fluorite for use in making the finer and more expensive apochromats. It therefore appears that a plentiful supply of optical fluorite would be of great benefit to the microscope industry, as thus far the output of optical systems containing fluorite has been limited simply by an insufficient supply of this

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5 - Pogue, J. E., Optical Fluorite in Southern Illinois: Extract from Bull. 38, State Geological Survey Division, University of Illinois, 1918, 8 pp.

6 - The writer (Pogue) is indebted to the Bausch and Lomb Optical Co., the Spencer Lens Co., and the Bureau of Standards for details in regard to the use of optical fluorite.

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material. The development of adequate sources of optical fluorite therefore becomes a matter of considerable importance, affecting ultimately through cheaper and more efficient microscopes the progress of scientific and medical research.

Optical fluorite is also used in making prisms for spectrographs employed in ultra-violet work and for use in other optical apparatus in cases where great transparency to the ultra-violet and the infra-red parts of the spectrum is required. It is likewise employed as part of the lens-system in telescopes to correct certain color effects. Specimens suitable for such highly specialized uses as those mentioned in this paragraph are difficult to obtain, because of the comparatively large size of pieces required; but the demand for such material is rather limited in an economic sense, though very insistent and important for the furtherance of investigational activities. While practically all fluorite possesses the optical qualifications noted above, the vast preponderance of material is too strongly colored or else too clouded with internal fissures and inclusions to transmit light unaffected by these undesirable influences. Moreover, some clear and colorless specimens otherwise suitable for optical use are found to show an anomalous double refraction, due probably to abnormal conditions during crystallization, which renders them unfit. These incidental, rather than inherent properties, therefore, become the controlling factors in determining the availability of material, and consequently determine the practical specifications which prospective material must meet.

For optical use a specimen of fluorite must contain a portion at least one-fourth of an inch in diameter, free from flaws, and colorless or nearly so. Crystals, or pieces bounded more or less completely by plane surfaces, are more likely to qualify than irregular masses. As the surfaces of most crystals are dull, a corner of such a specimen should be broken off with a sharp blow so as to expose the interior. In doing this, it is desirable to rest the specimen on a wooden base and break off the corner along an incipient cleavage plane by means of a knife blade or chisel; such planes are usually present and may be located by moistening the specimen with kerosene. If the specimen looks promising, it is better to proceed no further, as fluorite is fragile and a midsirected blow will fill a clear piece with a network of fractures. A peculiarity of fluorite of optical quality is its conchoidal (irregularly curved) fracture and the absence of a strong tendency to break into pieces bounded by smooth planes in the fashion of the ordinary mineral.

***. As to color, material that is absolutely water-clear is of course the most desirable, and in fact is essential for highly specialized uses; but faint tints of green, yellow, and purple do not in themselves render material altogether unsuited for optical use. Flaws must be lacking from the portion to be used, but flaws are present in the bulk of fluorite, due both to cracks (incipient cleavages) and to

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inclusions of bubbles or of visible impurities; accordingly the most detailed search is necessary to find pieces free from these objections. Moreover, careless handling, even jolts resulting from shipping, may develop flaws in clear material; hence the utmost care must be exercised in separating material of optical promise from its crude associations and in suitably packing such material.

The anomalous double refraction shown by some specimens, particularly by symmetrical crystal groups known technically as "twin-crystals," bars such material from optical use; but this property can be determined only by a microscope or other optical instrument at the eye of a trained observer. A clue to this condition is given in some cases by fine, parallel striations or rulings, marking a twinned condition of crystallization. In general, however, the clear specimens of southern Illinois fluorite already examined have been largely free from double refraction; hence for all practical purposes this test may be ignored in the field and left to the optical dealer to apply at his discretion.

Geology

Fluorite is unusual in that it occurs under widely varying geologic conditions. Its most common occurrence is as vein material associated with sulphides or sulphates such as galena, sphalerite, and barite. Veins containing fluorite occur in association with igneous rock, both acid and basic, with schists, and with sedimentaries. Deposits filling veins or cavities in limestones are common.

Granites, syenites, and quartz porphyries may contain small quantities of primary fluorite, but these occurrences are of little importance except from a mineralogical viewpoint. Fluorite crystals have been found in lava flows.

The most extensive commercial deposits are those filling veins or partly replacing beds in limestones. The fluorite in either instance probably was formed by replacement of the calcium carbonate.

Production Methods

Fluorspar mining and milling methods have been thoroughly discussed in a previous publication[7] of the Bureau of Mines which is available in most libraries or can be purchased from the Superintendent of Documents, Washington, D. C.

The purpose of the present report is to call attention to the fact that an unsupplied market for optical fluorite exists. Fluorspar operators can not only increase their revenue but also render a service to science by instructing their staffs to watch for transparent crystals during development work, and by ordering the pickers to collect glassy fragments from the picking belts.

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7 - Ladoo, R. B., Fluorspar: Its Mining Milling, and Utilization, with a chapter on Cryolite: Bull. 244, Bureau of Mines, 1927, 184 pp., 35 cts.

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Prospectors also should be aware of the value of optical-grade spar. A shallow prospect pit may have a better chance of uncovering optical fluorite than an extensive deeper operation, for crystals of the best quality are usually found lining vugs and cavities near the surface.

Specimens must be handled carefully because optical fluorite is almost as fragile as Iceland spar. Trimming should be minimized in order to avoid fracturing of the crystals. Shipments should be packed in wooden boxes with each specimen wrapped separately in order to prevent damage in transit. It is usually desirable to submit samples of the material to the prospective buyer before actual shipment is made. The samples should be representative of the entire quantity available and not crystals tediously selected because of their transparency and perfection. Otherwise the consumer may reject part or all of the material sent to him because it is below the standard of the original sample.

Consumption and Prices

No statistics regarding optical fluorite consumption are available but the market is such that, at present, it is safe to state that all high-grade optical fluorite that can be produced is readily salable. This refers only to crystals or cleavage fragments which are absolutely transparent and entirely free from flaws or fractures. Several hundred pounds of the material is sold annually to optical manufacturers and mineral dealers, but the demand no doubt would be increased if supplies of suitable material were available.

The unit value of optical fluorite varies considerably depending directly upon the size of the flawless pieces. The price during the past few years has fluctuated from $1 to $10 a pound for material of average quality, but especially fine specimens may be sold for $10 or more each. Only about 5 per cent of the fluorspar sold as optical material actually is consumed in lenses and other equipment. For this reason one manufacturer has adopted a policy of paying only for the finished parts. On this basis one crystal may be used satisfactorily for two or three lenses and be paid for at a rate comparable to $50 or $75 a pound, while 25 or 30 pounds of fluorspar ordinarily sold as optical fluorite may bring only $4 or $5. This system of payment encourages more careful selection of crystals and eliminates much material which obviously is too imperfect for optical use. The actual price for each transaction usually is established by negotiation with the prospective consumer or dealer.

Markets

The ultimate markets for optical fluorite are essentially the same as those for Iceland spar. The manufacturers of optical equipment and the mineral dealers included in the lists given in the section devoted to Iceland spar are also potential buyers of optical fluorite. Fluorspar, however, differs from calcite in its chemical uses, therefore the suggested markets for Iceland spar as standardizing material are not applicable to optical fluorite.

Occurrences

No attempt will be made in this paper to describe any deposits of fluorspar in detail, because most of the important occurrences have been discussed in various reports[8]

8 - For bibliography see: Davis, H. W., Fluorspar and Cryolite: Mineral Resources of the United States, 1924, Bureau of Mines, 1927, p. 74.

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already available. In 1929 production of fluorspar was reported[9] from Colorado, Illinois, Kentucky, Nevada, and New Mexico. Every mine in each of these localities is a potential source of supply of optical fluorite, but only a few of the operators make any effort toward recovering the material. Practically all of the optical fluorite which is now produced commercially in the United States comes from the deposits in southern Illinois.

Fluorspar suitable for the optical trade is reported from the Madoc district of Canada, from Switzerland, and from Japan. German manufacturers evidently depend upon the foreign deposits for their supply.

Although the value of optical fluorite is practically negligible from the standpoint of total financial returns, it is of extreme importance in scientific research. The consumers should cooperate with the dealers in maintaining a price sufficiently high to encourage production and in educating the producers to differentiate between ordinary fluorspar and optical-grade material. The dealers, on the other hand, should realize that it is to their advantage to build up a substantial market for this material rather than to hold out for exorbitant prices on a few crystals.

Both Iceland spar and optical fluorite are specialized products that are worth the consideration of every person who is able to aid their commercial production.

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9 - Davis, H. W. Fluorspar and Cryolite in 1929: Mineral Resources of the United States, 1929, Bureau of Mines, 1930, pp. 1-21.

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ICELAND SPAR AND OPTICAL FLUORITE

BY

H. HERBERT HUGHES

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UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

ICELAND SPAR AND OPTICAL FLUORITE[1/]

By H. Herbert Hughes[2/]

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ICELAND SPAR

Introduction

Iceland spar is a variety of calcite (calcium carbonate) characterized by its purity, transparency, and perfection of crystalline structure. It takes its name from the country in which it was discovered. The actual demand for it is small, but the supplies of high-grade optical spar are so meager that the search for it has become international in scope. Iceland spar is a scientific necessity, for without it research precision and technology would be hampered considerably. It has been reported, however, that polaroid glass may be used to some extent as a substitute.

1/ The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 6468R." (Originally published in July 1931.)

2/ Chief economist, Mineral Production and Economics Division, Bureau of Mines.

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The earliest students of mineralogy were familiar with calcite, but the transparent variety was not discovered until early in the seventeenth century, when crystals of it were found in the bed of a stream in Iceland. It received little attention until 1669, when Erasmus Bartholinus first recognized its powers of double refraction. The results of his investigation were published in a book, "Experimenta Crystalli Islandici," which appeared in 1670. The law governing the action of the refracted rays was discovered by Christian Huygens 8 years later.

The polarization of light rays in passing through Iceland spar was discovered in 1809 by Etienne Louis Malus, a French physicist, who published a paper describing the phenomenon. His work was followed closely by that of William Nicol, who in 1828 designed the Nicol prism, which is still used as the source of polarized light in most optical instruments.

Acknowledgment

Much of the information contained in this paper was taken from a report on Iceland spar by Oliver Bowles3/, which is no longer available.

Uses

By far the most important use of Iceland spar is for the manufacture of Nicol prisms, which are an essential part of every polarizing microscope and which are used also in saccharimeters, dichroscopes, photometers, colorimeters, and polariscopes.

An ordinary light ray is extremely complex; its vibrations take place in all possible planes intersecting the ray as an axis. When such a light ray passes through a rhombohedron of calcite, however, it is resolved into two rays of plane polarized light, each vibrating in a single plane perpendicular to the other. Furthermore, the two rays have different indexes of refraction, which result in their following different paths through the crystal. This phenomenon can be observed by placing a cleavage fragment of calcite over a dot on a piece of paper. Two dots will appear and, upon rotating the crystal, one will revolve around the other. These two rays are commonly known, respectively, as the ordinary and the extraordinary.

The Nicol prism is an ingenious device that utilizes these properties in providing a source of plane polarized light. It is constructed of clear, flawless calcite in such a manner that the ordinary ray is reflected and totally absorbed within the Nicol, while the extraordinary ray emerges as polarized light vibrating in only one plane. A cleavage rhombohedron of Iceland spar about three times as long as it is broad is cut diagonally along the plane connecting the obtuse dihedral angles of two opposite elongated faces, and the end surfaces are ground down until they are perpendicular to this newly formed plane. The two halves

3/ Bowles, Oliver, Iceland spar: Bureau of Mines Rept. of Investigations 2238, 1920, 6 pp.

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are then cemented together with Canada balsam, a transparent cement having an index of refraction lying between the values of the indexes of the two rays common to calcite. The cemented Nicol is polished and then set in cork, blackened along the contact with the calcite so as to absorb light that is reflected to the sides.

Immediately upon entering the Nicol any ray of white light is broken into two rays, the ordinary and the extraordinary. The ordinary ray has a higher index of refraction and, therefore, it is refracted to a greater extent than the extraordinary. As a result it meets the Canada balsam at an angle so great that it is reflected from it and is absorbed by the blackened walls of the prism. The extraordinary ray, because of its lower index of refraction in this direction through the crystal, meets the Canada balsam at a lesser angle and passes through it without being affected appreciably. This ray emerges from the opposite end of the Nicol as plane polarized light with its vibration plane parallel to the short diagonal of the rhombic section of the prism and polarized in the plane parallel to the film of Canada balsam. This vibration plane is rigidly fixed by the crystalline structure of the calcite. Modifications of this style of Nicol have been devised, but they all embody the principle of totally reflecting either the ordinary or the extraordinary ray.

By means of the petrographic microscope, which uses two Nicol prisms, the behavior of polarized light in traversing thin sections of minerals can be studied. The optical properties thus revealed provide an accurate means of identification for most minerals. Iceland spar, therefore, is of inestimable value in the scientific investigation of rocks and minerals. Nicol prisms or modifications of them are used in other scientific equipment, which aids manufacturers in keeping a close check on the quality and uniformity of their products. Among these instruments are saccharimeters, which are used to measure the sugar content of a solution; colorimeters, which indicate depth of color as compared with a standard; photometers, which measure intensity of light; dichroscopes, which reveal dichroism in crystals; polariscopes and polarimeters, which are used in the study of polarized light; spectrometers, which are used in determining index of refraction; and spectroscopes, which are used in forming and examining spectra. Iceland spar is used also in the determination of crystal structure by X-ray analysis.

Only a small percentage of the spar recovered from most deposits is of optical grade, and unfortunately there is virtually no market for material that is too cloudy or otherwise too imperfect for optical use. Many fine crystals of Iceland spar have been acquired by various museums, but this market is in direct competition with optical manufacturers. Probably the finest specimen is that in the British Museum. It is a section of a large crystal about 24 inches across and at least 16 inches thick, virtually free from fractures or inclusions. The crystal was taken from the Iceland deposit during the early years of its operation.

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Numerous smaller specimens are sold to museums, colleges, schools, or private collectors either as additions to mineral collections or for demonstration of optical properties. This market provides an outlet for material that is slightly inferior to high-grade optical spar. The quantity actually consumed for these purposes, however, is small compared with the waste material available at most deposits, and prices are low; hence, sale of collection specimens has little effect on the lowering of unit production costs.

A small quantity of chemically pure Iceland spar is consumed by manufacturing chemists in the preparation of standardizing solutions for use in volumetric analysis. The demand for standardizing spar is small, although it is possible that a thorough canvass of the chemical industries might establish a market that would absorb much of the waste material.

Pure calcium carbonate is used also in the manufacture of special kinds of glass, as whiting substitute, in the preparation of chemical lime, as a filler in various products, and for numerous other purposes; but for these uses optical properties are nonessential, and the markets are being supplied with high-grade limestone or marble, which can be produced in large quantities for only a few dollars a ton.

The auxiliary uses of Iceland spar are comparatively insignificant, and anyone contemplating the exploitation of a spar deposit should assure himself that enough optical-grade material to warrant the cost of development is available.

Physical Properties

Two properties of Iceland spar must be considered carefully by those mining and handling the material. One is its perfect rhombohedral cleavage. Iceland spar splits in three directions at oblique angles. Every cleavage fragment, regardless of its size, possesses this rhombohedral form, resembling a brick that has been pushed over from one corner when soft, with the result that the whole brick is lopsided. Although this cleavage necessitates using extreme care in mining the material, it is decidedly helpful in trimming rough crystals and in breaking up large masses. This work, however, should be done by an expert thoroughly familiar with the properties of calcite, for one misdirected blow may cause incipient fractures throughout the crystal and entirely ruin it for optical use.

The other property is hardness. Iceland spar is merely pure, crystallized limestone; therefore it is quite soft and can easily be cut or scratched with a knife. In packing for shipment each piece should be wrapped separately to prevent abrasion of crystals against each other or against the sides of the container.

Specifications for Iceland spar suitable for optical uses are rigid. The crystals or cleavage fragments must be at least 1 inch long and half an inch thick each way. Pieces smaller than this are rarely acceptable

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as optical spar. Each piece must be colorless and absolutely transparent, completely free from cloudy inclusions, cavities, or foreign particles. The material must not show any internal iridescence or rainbow colors due to incipient cracks along cleavage planes. Even twinning lamellae that are invisible to the naked eye may ruin some specimens for optical use. The imperfections and inclusions are not always scattered throughout the entire crystal, and each specimen should be examined from every direction to detect the presence of all defects. It is sometimes possible to trim away imperfect portions of large crystals and recover cleavage fragments of satisfactory spar. Whenever feasible, all trimming should be done by experienced persons.

A twin crystal can be identified by placing it over a dot on a piece of paper. If the crystal is normal, two dots will appear, which will vary little regardless of movement of the crystal along the paper. In moving a twin crystal slowly back and forth, however, additional indistinct dots may also appear in various positions. Twinning ordinarily ruins a crystal for optical use, but it is possible in some instances to cut the crystal in such a manner that the undesirable twinning phenomena are eliminated.

Geology

Iceland spar is formed by deposition of calcium carbonate from water solution, but the conditions necessary for the formation of transparent spar rather than ordinary calcite are not definitely known. No blanket statement covering geologic occurrence of the material can be made. In general, however, the principal deposits are associated with basic igneous rocks occurring as masses or crystal aggregates in cavities of the country rock. These pockets usually are filled with residual clay. The belief that the calcite has been deposited from magmatic (deep-seated) rather than meteoric solutions has many adherents, but there is little evidence to support this theory. Other minor deposits of Iceland spar, usually of inferior quality, occur as vein material in limestones and related rocks.

Mining Methods

Ordinary open-pit methods of mining have been used in most Iceland-spar operations. The country rock is broken up by explosives, after which the clay pockets are worked out by hand to recover the spar crystals. These, in turn, may be broken by small hand hammers into pieces more easily handled. Iceland spar is shattered easily, and this rough treatment undoubtedly is responsible for a large proportion of the incipient fractures in the finished product. The use of explosives in mining this material can not be condemned too strongly, for even though the masses of spar may be partly cushioned by the clay surrounding them, blasting ruins many of the crystals.

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The best method of mining could be determined only by a careful study of the deposit itself. Most marble deposits are worked by channeling and wedging, without the use of explosives, so as to avoid fracturing the material. Careful handling certainly is more important with Iceland spar than with building and ornamental stone. Marble-quarrying methods might be applied advantageously to spar deposits. A channeling machine could be used to make wall cuts along the sides of the veins, after which large masses of the rock could be split off by drilling and wedging. Subsequent reduction in size of fragments might be accomplished best by means of wooden wedges and mallets. Most Iceland-spar operations are too small to justify the expense of a channeling machine, but a substitute method of wedging in drill holes might be applied. Regardless of the mining method selected, the operator always should bear in mind that the fragile nature of the material demands extreme care throughout the entire procedure.

An interesting departure from conventional quarrying methods is the use of unslaked lime rather than explosives in breaking the rock surrounding the crystals. This procedure eliminates the danger of fracturing the spar by blasting. The method is simple. Three or four inches of unslaked lime is tamped in the bottom of a hole drilled a short distance from the crystals. A slender iron rod or wire is inserted into the hole, and lime is packed around it to within 2 inches of the top by means of a curved tamping bar. The rod is then removed, and a cotton string saturated with water is dropped into the hole so that the end is suspended about half an inch off the bottom. The opening of the hole is then sealed with clay or some other similar material. The water dripping from the string causes expansion of the lime, which bursts the rock with a minimum of damage to the spar. This method was suggested to the Bureau in 1929 by Oscar H. V. Berghland of California.

A system of underground mining was at one time being considered for the Iceland deposit. The principal advantages of the proposed plan were that it would permit continuous operation throughout the year, workmen would be sheltered from inclement weather, the danger from rock falls would be reduced, and the spar crystals would be protected from frost and other weathering agencies. These features were particularly applicable to the Iceland mine, for the rigorous Icelandic winters greatly hamper any outdoor activities. However, the possibility of underground mining should not be overlooked during the development of any deposit, providing that the operator has done enough exploration work to assure himself that the reserves of material justify the investment.

Consumption and Prices

Before the World War European companies, particularly German firms, supplied virtually all of the Nicol prisms and other Iceland spar parts used by American manufacturers of scientific apparatus. During the war, however, rapid depletion of stocks of finished prisms forced the American companies into the manufacture of these essential parts. During the post-war period domestic production of Nicol prisms has been supplemented by imports, and normally there is a ready market both in the United States and abroad for high-grade optical spar.

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No production or consumption figures for Iceland spar are available, but the quantity actually sold in the United States is small, probably not more than 200 or 300 pounds a year. The volume of foreign consumption normally has been considerably greater.

No definite price for Iceland spar can be quoted. In many transactions a fair price is arrived at by negotiation between the buyer and seller. The principal factors influencing price are the quality of the spar, the size of the fragments or crystals, and the quantity to be sold. The status of the reserve supplies of the purchasing company exerts a pronounced influence on prices; a manufacturer with a large reserve of optical spar will not pay as high a price as another manufacturer whose supplies are nearly exhausted. The price of optical-grade spar in past years has fluctuated from $7 to $35 a pound. Seasonal trends and general business depressions have little effect on Iceland spar.

The average price for museum or collection specimens is about $1 to $3 a pound, although the value of extra-fine crystals is equivalent to that of optical-grade material. Standardizing spar usually sells for $1 to $2 a pound.

Markets

Several companies in the United States manufacture scientific equipment, but only the following two firms are consumers of Iceland spar.

Bausch & Lomb Optical Co., 626 St. Paul Street, Rochester, N. Y.
Spencer Lens Co., 19 Doat Street, Buffalo, N. Y.

The following foreign manufacturers of optical instruments have been potential buyers of high-grade spar when world conditions were favorable for international trade.

Carl Zeiss, Jena, Germany (Sales Office: 485 Fifth Avenue, New York, N. Y.).
E. Leitz, Wetzlar, Germany (Sales Office: 60 East Tenth Street, New York, N. Y.).
C. P. Goertz, Stuttgart, Germany.
I. C. A. A. G., Stuttgart, Germany.
Contessa Nettel A. G., Stuttgart, Germany.
Ernemann A. G., Dresden, Germany.
Hollain & Reinhardt, Neuhausrennweg, Germany.
Kroger & Ihlenfeld, Blankanese, Germany.
Adam Hilger, Ltd., 75a. Camden Road, London, England.
Short & Mason, Ltd., London, England.
Societe Genevoise d'Instruments de Physique, Geneva, Switzerland.

Mineral dealers constitute an outlet for small quantities of Iceland spar, both for optical-grade material and for museum or collection specimens.

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Some of the most important companies engaged in the mineral supply business are given in the following list.

Southwest Gem & Jewelry Co., Metropolitan Bldg., Los Angeles, Calif.
A. B. McAntire, 7721 South Main St., Los Angeles, Calif.
R. M. Wilkie, Palo Alto, Calif.
S. & M. Mineral Supply House, R. F. D. 3, Box 284, Riverside, Calif.
Dunneen Marble Works, 645 40th St., Oakland, Calif.
West Coast Curio Co., Costa Mesa, Calif.
John M. Grieger, 405 Ninita Parkway, Pasadena, Calif.
F. G. McIntosh, 841 Greenway Drive, Beverly Hills, Calif.
W. Scott Lewis, 2500 N. Beachwood Drive, Hollywood, Calif.
John H. Esselink, Sebastopol, Calif.
A. G. Pohndorf, 400 17th St., Denver, Colo.
Standard Science Supply Co., 11 E. Austin Ave., Chicago, Ill.
Lundholm and Co., 3303 Foster Ave., Chicago, Ill.
E. M. Gunnell, 538 Monmouth Blvd., Galesburg, Ill.
R. W. Tuthill, 110 Earl Road, Michigan City, Ind.
Boodless Mineral Specimens, Box 331, Galena, Kansas.
Perham's Maine Mineral Store, West Paris, Maine.
The Mineral Novelty Co., Box 1005, Joplin, Mo.
The Gem Shop, Box 797, Helena, Mont.
American Gem & Pearl Co., 6 West 48th St., New York, N.Y.
John A. Grenzig, 299 Adams St., Brooklyn, N. Y.
A. D. Mackay, 198 Broadway, New York, N. Y.
A. J. Rimberg Co., 117 Liberty St., New York, N. Y.
Eimer & Amend, 201 East 13th St., New York, N. Y.
Peter Zodac, Peekskill, N. Y.
Ward's Natural Science Establishment, Rochester, N. Y.
Lucian M. Zell, 522 Fifth Ave., New York, N. Y.
H. G. Clinton, Manhattan, Nev.
Kenneth J. Crawford Co., 220 Avenue A, West Bismarck, N. Dak.
W. J. Parquette, 417 Fourth St., Toledo, Ohio.
John M. Tracy, 601 Orange St., Portland, Oreg.
Foote Mineral Co., 1610 Summer St., Philadelphia, Pa.
Wm. Parish, 2567 Amber St., Philadelphia, Pa.
Mrs. Edna M. Scott, Box 44, Custer, S. Dak.
D. P. Brim, Mitchell, S. Dak.
John B. Litsey, P. O. Box 592, Dallas, Texas.
C. L. Brock, P.O. Box 1492, Houston, Texas.

No attempt has been made to compile a complete list of possible buyers for standardizing spar because, although such firms are numerous, the quantity sold is small and the price is low. Any producer who is interested in building up such a market for waste spar will be able to find the principal chemical companies and chemists' supply houses listed in Thomas' Register of American Manufacturers or in the Chemical Engineering Catalog, which are available at most libraries, Chambers of Commerce, and offices of other trade associations.

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Occurrences

Deposits of Iceland spar have been reported in many of the Western States and in several foreign countries, but actual commercial production at present seems to be confined to New Mexico, South Africa, and possibly Spain. The known reserves of optical spar available in this country are small. No complete list of Iceland-spar producers can be compiled, but the following descriptions of the principal deposits include a summary of the present status of each occurrence as well as names and addresses of persons who can furnish either optical spar or further information.

Iceland

The spar mine in Iceland is now largely of historical interest only. It is near the farm Helgustadir, about one hour's ride from Eskifjordur, a trading station on the east coast of the island. The deposit lies approximately 345 feet above sea level.

The deposit was discovered during the early part of the seventeenth century, but little attention was given it prior to 1650. After the work of Bartholinus and Huygens it attracted considerable attention, but actual development of the property was not begun until 1850. At that time part of the deposit was privately owned and part owned by the Government, but in 1879 the Government obtained entire control, and all operations since then have been under Governmental supervision, either directly or by lease to native or foreign companies.

The country rock consists of a series of basalt-lavas in alternating beds of unaltered and decomposed rock. Numerous small crystals of calcite are found in the many joints and crevices of the basalt. Disintegration of the rock has formed larger openings in some parts of the deposit, and these cavities are partly filled with residual red clay. Crystals of the best quality are found embedded in this clay. The first large cavity discovered was reported to have been virtually filled with pure crystallized masses and enormous crystals, the largest being a yard across. The crystals are rhombohedral or scalenohedral in habit; the faces are usually well developed but are commonly coated with stilbite. Other zeolites occur around the edges of the clay pockets. The spar crystals that are unprotected by clay usually are imperfect.

Eiriksson's[4/] theory for the origin of the calcite is interesting. He contends that alteration of the basalt is not due to weathering but to the action of heated ascending waters, which probably also brought up much of the calcium carbonate. This theory is partly substantiated by the fact that the clay pockets seem to increase in size with depth, and further, that the crystals in the deeper cavities are larger and of better quality than those lying near the surface.

4/ Eiriksson, Helgi H., The Spar Mine at Helgustadir, Iceland: Trans. Inst. Min. Eng., London, vol. 59, March 1920, p. 56.

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No description of the Iceland quarry has been published since Eiriksson's report, but in 1919 the pit was 100 feet long and 72 feet wide at the top. The average depth was 52 feet and the bottom dimensions were about 55 by 50 feet. No definite order or system of development was followed, the clay pockets being worked out by hand with picks and shovels wherever they were found. The largest clay pockets containing the most perfect crystals were found in the southwestern corner of the pit. Undercutting in this corner left a dangerous overhang of rock, which made further progress in that direction extremely hazardous. Eiriksson strongly recommended that the open-pit method of mining be abandoned in favor of underground development.

Spar crystals from the Iceland mine are variable in size, and, as in every deposit, many of them are too imperfect for optical use. In addition to cracks and distortions the principal imperfections are air bubbles, included water, and streaks of clay or other foreign mineral matter. Operations were discontinued for several years during the World War, and the quarry was flooded to protect the crystals from weathering. After it was reopened the quality of the material was far below the standard of the pre-war product. As a result the deposit has been worked only intermittently, and the consumers have been forced to find supplies of optical-grade spar elsewhere. Careful subsurface exploration might reveal additional clay pockets containing high-grade material, but doubt has been expressed as to whether the cost of such an investigation would be justified.

South Africa

Demand for Iceland spar in recent years has been satisfied principally by South Africa. The most important locality has been the Kenhardt district, northwest Cape Province, where numerous deposits are scattered over a large area. The spar occurs as irregular masses of various sizes embedded in soft, sandy clay, which fills cavities in weathered diabase. The spar is recovered solely by hand methods. Iceland spar probably was discovered in South Africa first by early explorers, but its value was not recognized until about 1920, when small shipments were sent to Germany. Most of the material has been sold to German manufacturers, but it has also been imported into the United States. Production apparently is not continuous, but various persons have been working the material intermittently since 1922 or earlier.

Spain

About 1913 a small quantity of Iceland spar was produced in Spain and shipped to Germany by Felipe Azcarate of Bilbao. A shipment of material from this source was received in the United States, but it was found to be unsuited for optical uses. However, it was rated by the shipper as third-class spar, and therefore it can not be taken as representative of the material that was supplied to German manufacturers. It was reported that preparations for expansion of operations at this deposit were interrupted by the war of 1914-1918. No further information has been

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received regarding the site of the mine, the extent of the deposit, or present developments. However, shipments of optical-grade spar from Spain have been received in the United States at times. This would indicate renewal of mining activity, but it does not necessarily reveal the scope of the operation because most of the production might logically be consumed in European markets.

Canada

Glenn, Kirkpatrick, and Armstrong of Beaton, B. C., reported an occurrence of Iceland spar to Norton F. Brand, American consul, Fernie, B. C., in 1921. The deposit was near the headwaters of Lake Creek in the Trout Lake mining district, about 20 miles from Ferguson. In 1930 Brand stated that all three of the discoverers had since died and that the claims probably are abandoned. Estimates of the quality of the spar are conflicting, but the locality may merit further investigation.

In 1921 J. B. Woodworth of Vancouver, B. C., submitted samples from a deposit near Kamloops, B. C. The material appeared to be of good quality, although some of it was highly fractured. The cracks may have been caused by trimming. The crystals are said to occur in veins in limestone and are associated with clay.

South America

In 1920 samples of Iceland spar from Buenos Aires, Argentina, were sent to the United States to be tested for use in optical equipment. It was reported that the quality of the material was good enough to warrant investigation of the source of supply. Nothing further seems to be known regarding the deposit, and it may have been of no importance.

One of the American manufacturers reported in 1921 that Iceland spar could be purchased in Brazil, but no further details regarding its occurrence in that country have been forthcoming.

United States

Greycliff, Mont. - Deposits of Iceland spar near Greycliff and Big Timber in Sweet Grass County, Montana, were first reported to the Bureau of Mines in 1916. Samples of the spar received at that time indicated that the material had commercial possibilities, and S. C. Lind, a member of the staff of the Bureau of Mines Experiment Station at Golden, Colo., investigated the deposit. Most of the information given in this description has been taken from Dr. Lind's report.

The spar was first discovered by W. E. Burch about 1907. The deposit he found is about 12 miles southwest of Greycliff, which is on the main line of the Northern Pacific Railroad 71 miles west of Billings. A shaft was sunk to a depth of about 75 feet, and 30 or 40 tons of calcite was taken out. About 600 pounds of the best material was shipped to New York and ultimately to Germany. Another deposit about 1 mile closer to Greycliff

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was opened later by R. H. Cartwright, and samples of the best crystals were sent to London and Philadelphia. No report of the optical properties of the spar is available from either source. A third deposit was discovered about 10 miles west of Greycliff and 4 miles from Big Timber.

The spar at the Cartwright operation, which is the largest deposit, occurs in two parallel vertical veins striking northwest and southeast. One is about 7 feet wide and the other 5 feet. They apparently extend for several miles, maintaining their width and direction with remarkable constancy. The depth of the veins is not known, but there is evidently a large reserve supply of spar. There is little overburden, and the vein is nearly all calcite.

Chemically the spar is virtually pure calcium carbonate, but most of the material has not been suitable for optical uses. Three kinds of imperfections are prevalent. Some of the crystals are cloudy, but as this turbidity affects only a small percentage of the material it is of no serious consequence. The principal defect is the abundance of incipient cleavage cracks in the interior of the crystals which render much of the spar unfit for optical uses. The cracks may be due partly to rough handling, but many of them appear to be inherent in the calcite. Many of the crystals are complexly twinned.

Little can be learned about the subsequent status of the operation. R. H. Cartwright, Greycliff, Mont., and Professor J. P. Rowe, Missoula, Mont., worked the deposit intermittently for several years and sold a small quantity of optical spar. From the nature of the material, it seems logical to assume that the preponderance of imperfect crystals made production costs too high for economical operation. From the standpoint of reserves, however, the location is interesting, for in an emergency when foreign supplies are not available optical spar could no doubt be produced.

Cedarville, Calif. - The occurrence of Iceland spar in the Warner Range near Cedarville, Modoc County, Calif., was first brought to the attention of the Bureau of Mines by James D. Patterson in 1920. This deposit was worked intermittently for a few years, but production was discontinued before 1925.

This occurrence was never studied by any Bureau representative, but reports from the operators indicate that the calcite occurred in veins or cavities varying in thickness from a few inches to several feet, the country rock being dark and heavy, probably a basalt. Nearly all the pockets or cavities contained crystals of Iceland spar, the larger crystals occurring in soft decomposed rock of the consistency of clay. Unfortunately, however, the deposit was shallow and the quantity of spar recovered from the operation was much less than the owners anticipated. Specimens ranged in size from a marble to large crystal aggregates weighing 60 to 80 pounds. Nearly all of the clear crystals were covered with a reddish coating having a burned appearance, and they emitted a characteristic ringing sound when struck with a hammer. Many of the crystals were twinned. All mining was by open cut.

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No statistics are available regarding the total quantity of optical-grade spar produced. During the winter of 1920-1921, which was apparently the most active year, about 1,000 ounces of spar was sold. The price was $8 a pound for pieces weighing 1 ounce, with a premium of 50 cents additional for each one-fourth ounce increase in weight of the crystals. The largest crystal shipped during that year weighed 12 ounces. The percentage of flawless crystals was low, but they were of excellent quality and gave satisfactory service in optical instruments. At the time of its discovery this deposit was expected to constitute an important source of supply of optical spar, but its limited extent prevented extensive development. No production has been reported during recent years.

Pyramid Lake, Nev. - James D. Patterson was also responsible for the discovery of an Iceland-spar deposit near Pyramid Lake, Nev. It was reported to be geologically similar to the Cedarville deposit, but was found to be of limited extent and no commercial importance.

Taos, N. Mex. - Much interest has been centered recently on a deposit of Iceland spar in the Copper Mountain Mining District, Taos County, N. Mex., about 30 miles southwest of Taos. As described by J. Harlan Johnson in The Mines Magazine (Denver, Colo.) for February 1940, the Iceland spar occupies a tubular or conical space about 20 feet in diameter at the surface. It is situated on a fault plane. Although much calcite is present, that of commercial quality for optical purposes constitutes a relatively small part of the total and is confined to border crystals that have grown into a clayey, decomposed schist. No estimate of the extent of reserves is available. Optical companies have used the material and report that it is of excellent quality. The present operators are E. M. Stanton and his associates, Santa Fe, N. Mex.

Miscellaneous. - Numerous samples of Iceland spar submitted to the Bureau of Mines for examination approach optical-grade material, but none of the specimens has been perfect enough to be satisfactory for optical uses. Most of the alleged deposits are in the Western States. Some of the calcite commonly associated with the zinc and lead ores of the Joplin district is almost transparent and perfect enough to be classed as Iceland spar. No optical use of it, however, has been reported to the Bureau.

OPTICAL FLUORITE

Introduction

Fluorite (calcium fluoride) is a mineral used extensively as a flux in the metallurgical industries and to a lesser extent in the manufacture of hydrofluoric acid, glazes, enamels, and opalescent glass. It is commonly known to the trade as fluorspar.

Fluorite is slightly harder than Iceland spar, but it can be scratched easily with a knife. A diagnostic difference between the two minerals is cleavage. Fluorite has perfect cleavage in four directions. Each fragment is a double, four-sided pyramid commonly known as an octahedron.

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Like Iceland spar, it is used in the manufacture of optical instruments; transparent, flawless crystals are sold at premium prices for use in lenses and lens systems to correct chromatic and spherical aberration.

Little seems to be known regarding the early use of fluorite in optical apparatus. At present, however, it is an essential part of many lenses and no doubt would be used more extensively if sufficient supplies of optical-grade material were available.

Properties and Uses

The following information regarding the properties and uses of optical fluorite is quoted from a paper by Joseph E. Pogue[5] which describes the optical fluorite resources of southern Illinois.

> Each transparent mineral not only bends or refracts rays of light in a definite and characteristic manner, but bends the colored components of the individual rays at slightly different angles - a property called dispersion. In addition to this, most minerals break light into two rays, each of which is both refracted and dispersed; only minerals that crystallize in very symmetrical forms, such as cubes or octahedrons, do not show this double refraction. Fluorite bends light very slightly (has a low index of refraction), disperses light faintly (that is, its refraction of red rays differs only a little from its refraction of yellow rays and so on), and normally displays no double refraction. These three properties place fluorite in a unique position among minerals and fit it for a highly specialized optical use ***** ***** *****.
>
> Glass, of a special kind, is the dominant material used in all optical apparatus. By varying the chemical composition of the glass and the shape of the lenses and prisms made from it the various optical effects desired are obtained. Owing to the reflection of light from surfaces and a breaking up or dispersion of light in passing through a substance, errors are introduced, and to neutralize or minimize these errors calls for the best efforts of technical art and scientific knowledge. It is here that optical fluorite finds its chief use.[6] Due to its low refractive power and very weak color dispersion, this mineral is especially suitable for correcting the spherical and chromatic errors of lens-systems. The so-called apochromatic objective used with microscopes consists of a lens of fluorite placed between lenses of glass and represents the finest type of

5/ Pogue, J. E., Optical Fluorite in Southern Illinois: Extract from Bull. 38, State Geol. Sur. Div., University of Illinois, 1918, 8 pp.

6/ The writer (Pogue) is indebted to the Bausch & Lomb Optical Co., the Spencer Lens Co., and the Bureau of Standards for details regarding use of optical fluorite.

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objective that optical art produces. There are two other classes of objectives, less fine and less costly, the achromat and the semiapochromat; fluorspar is used only in the second of these, which is a sort of compromise between the cruder achromat and the more nearly perfect apochromat. The less expensive semi-apochromat could replace the apochromat in many instances, were optical fluorite more available; but at present the manufacturer is forced to conserve his meager supplies of fluorite for use in making the finer and more expensive apochromats. It therefore appears that a plentiful supply of optical fluorite would be of great benefit to the microscope industry, as thus far the output of optical systems containing fluorite has been limited simply by an insufficient supply of this material. The development of adequate sources of optical fluorite, therefore, becomes a matter of considerable importance, affecting ultimately through cheaper and more efficient microscopes the progress of scientific and medical research.

Optical fluorite is also used in making prisms for spectrographs employed in ultra-violet work and for use in other optical apparatus in cases where great transparency to the ultra-violet and the infra-red parts of the spectrum is required. It is likewise employed as part of the lens-system in telescopes to correct certain color effects. Specimens suitable for such highly specialized uses as those mentioned in this paragraph are difficult to obtain, because of the comparatively large size of pieces required; but the demand for such material is rather limited in an economic sense, though very insistent and important for the furtherance of investigational activities. While virtually all fluorite possesses the optical qualifications noted above, the vast preponderance of material is too strongly colored or else too clouded with internal fissures and inclusions to transmit light unaffected by these undesirable influences. Moreover, some clear and colorless specimens otherwise suitable for optical use are found to show an anomalous double refraction, owing probably to abnormal conditions during crystallization, which renders them unfit. These incidental rather than inherent properties, therefore, become the controlling factors in determining the availability of material and consequently determine the practical specifications which prospective material must meet.

For optical use a specimen of fluorite must contain a portion at least one-fourth of an inch in diameter, free from flaws, and colorless or nearly so. Crystals, or pieces bounded more or less completely by plane surfaces, are more likely to qualify than irregular masses. As the surfaces of most crystals are dull, a corner of such a specimen should be broken off with a sharp blow so as to expose the interior. In doing this it is desirable to rest the specimen on a wooden base and break off the corner along an incipient cleavage plane by means of a knife

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blade or chisel; such planes are usually present and may be located by moistening the specimen with kerosene. If the specimen looks promising it is better to proceed no farther, as fluorite is fragile and a misdirected blow will fill a clear piece with a network of fractures. A peculiarity of fluorite of optical quality is its conchoidal (irregularly curved) fracture and the absence of a strong tendency to break into pieces bounded by smooth planes in the fashion of the ordinary mineral.

***. As to color, material that is absolutely water-clear is, of course, the most desirable and, in fact, is essential for highly specialized uses; but faint tints of green, yellow, and purple do not in themselves render material altogether unsuited for optical use. Flaws must be lacking from the portion to be used, but flaws are present in the bulk of fluorite, owing both to cracks (incipient cleavages) and to inclusions of bubbles or of visible impurities; accordingly, the most detailed search is necessary to find pieces free from these objections. Moreover, careless handling, even jolts resulting from shipping, may develop flaws in clear material; hence, the utmost care must be exercised in separating material of optical promise from its crude associations and in suitably packing such material.

The anomalous double refraction shown by some specimens, particularly by symmetrical crystal groups known technically as "twin crystals," bars such material from optical use; but this property can be determined only by a microscope or other optical instrument at the eye of a trained observer. A clue to this condition is given in some cases by fine, parallel striations or rulings, marking a twinned condition of crystallization. In general, however, the clear specimens of southern Illinois fluorite already examined have been largely free from double refraction; hence, for all practical purposes this test may be ignored in the field and left to the optical dealer to apply at his discretion.

Geology

Fluorite is unusual in that it occurs under widely varying geologic conditions. Its most common occurrence is as vein material associated with sulfides or sulfates such as galena, sphalerite, and barite. Veins containing fluorite occur in association with igneous rock, both acid and basic, with schists, and with sedimentaries. Deposits filling veins or cavities in limestones are common.

Granites, syenites, and quartz porphyries may contain small quantities of primary fluorite, but these occurrences are of little importance except from a mineralogical viewpoint. Fluorite crystals have been found in lava flows.

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The most extensive commercial deposits are those filling veins or partly replacing beds in limestones. The fluorite in either instance probably was formed by replacement of the calcium carbonate.

Production Methods

Fluorspar mining and milling methods have been discussed thoroughly in previous publications 1/ of the Bureau of Mines, which are available in most libraries.

The purpose of the present report is to call attention to the fact that at times an unsupplied market for optical fluorite exists. Fluorspar operators not only can increase their revenue but also render a service to science by instructing their staffs to watch for transparent crystals during development work and by ordering the pickers to collect clear fragments from the picking belts.

Prospectors also should be aware of the value of optical-grade spar. The chances of uncovering optical fluorite may be better in a shallow prospect pit than in an extensive deeper operation, for crystals of the best quality usually are found lining vugs and cavities near the surface.

Specimens must be handled carefully because optical fluorite is almost as fragile as Iceland spar. Trimming should be minimized to avoid fracturing of the crystals. Shipments should be packed in wooden boxes with each specimen wrapped separately to prevent damage in transit. It is usually desirable to submit samples of the material to the prospective buyer before shipment is made. The samples should be representative of the entire quantity available and not crystals tediously selected because of their transparency and perfection. Otherwise the consumer may reject part or all of the material sent to him because it is below the standard of the original sample.

Consumption and Prices

No statistics regarding optical-fluorite consumption are available, but the market is such that at present it is safe to state that all high-grade optical fluorite that can be produced is readily salable. This refers only to crystals or cleavage fragments that are absolutely transparent and entirely free from flaws or fractures. Several hundred pounds of the material is sold annually to optical manufacturers and mineral dealers, but the demand no doubt would be increased if supplies of suitable material were available.

1/ Ladoo, R. B., Fluorspar: Its Mining, Milling, and Utilization, with a Chapter on Cryolite: Bureau of Mines Bull. 244, 1927, 184 pp.
Hatmaker, Paul, and Davis, Hubert W.: The Fluorspar Industry of the United States, With Special Reference to the Illinois-Kentucky District: Illinois State Geol. Sur. Bull. 59, 1938, 128 pp.

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The unit value of optical fluorite varies considerably depending directly upon the size of the flawless pieces. The price during the past few years has fluctuated from $1 to $10 a pound for material of average quality, but especially fine specimens may be sold for $10 or more each. Only about 5 percent of the fluorspar sold as optical material actually is consumed in lenses and other equipment. For this reason one manufacturer has adopted a policy of paying only for the finished parts. On this basis one crystal may be used satisfactorily for two or three lenses and be paid for at a rate comparable to $50 or $75 a pound, while 25 or 30 pounds of fluorspar ordinarily sold as optical fluorite may bring only $4 or $5. This system of payment encourages more careful selection of crystals and eliminates much material that obviously is too imperfect for optical use. The actual price for each transaction usually is established by negotiation with the prospective consumer or dealer.

Markets

The ultimate markets for optical fluorite are essentially the same as those for Iceland spar. The manufacturers of optical equipment and the mineral dealers included in the lists given in the section devoted to Iceland spar are also potential buyers of optical fluorite. Fluorspar, however, differs from calcite in its chemical uses; therefore, the suggested markets for Iceland spar as standardizing material are not applicable to optical fluorite.

Occurrences

No attempt will be made in this paper to describe any deposits of fluorspar in detail, because most of the important occurrences have been discussed in various reports[8/] already available. Every mine is a potential source of supply of optical fluorite, but only a few of the operators make any effort to recover the material. Virtually all of the optical fluorite now produced commercially in the United States comes from deposits in southern Illinois.

Fluorspar suitable for the optical trade is reported from the Madoc district of Canada, from Switzerland, and from Japan. German manufacturers evidently depend on foreign deposits for their supply.

Although the value of optical fluorite is virtually negligible from the standpoint of total financial returns, it is of extreme importance in scientific research. Consumers should cooperate with dealers in maintaining a price high enough to encourage production and in educating producers to differentiate between ordinary fluorspar and optical-grade material. Dealers, on the other hand, should realize that it is to their advantage to build up a substantial market for this material rather than to hold out for exorbitant prices on a few crystals.

8/ For bibliography see, Davis, H. W., Fluorspar and Cryolite: Mineral Resources of the United States, 1924, Bureau of Mines, 1927, p. 74.

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Substitutes

Large, clear, carefully annealed crystals of lithium fluoride are said to be satisfactory substitutes for optical fluorite. A process for making exceptionally clear, perfect crystals was originally developed in the physical laboratories of Harvard University and Massachusetts Institute of Technology. The Harshaw Chemical Co., Cleveland, Ohio, further perfected the process and began production on a commercial basis of single crystals up to 2200 grams in weight in 1938. The Bureau of Mines has no data indicating the extent to which lithium fluoride crystals may be or are being substituted for natural fluorite.

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